Mercury Dust Monitor for the BepiColombo MMO

M. Kobayashi[1], H. Shibata[2], K. Nogami[3], M. Fujii[4], T. Miyachi[1], H. Ohashi[5], S. Sasaki[6], T. Iwai[7], M. Hattori[7], H. Kimura[8], T. Hirai[9], S. Takechi[10], H. Yano[11], S. Hasegawa[11], R. Srama[12] and E. Grün[12]

[1]Chiba Inst. Tech., [2]Kyoto Univ., [3]Dokkyo Medical Univ., [4]FAM Science, [5]Tokyo Univ. Marine Sci. Tech., [6]NAOJ, [7]Univ. Tokyo, [8]CPS, [9]Sokendai,[10]Osaka City Univ., [11]ISAS/JAXA, [12]Stuttgart Univ. [13]MPI-K.

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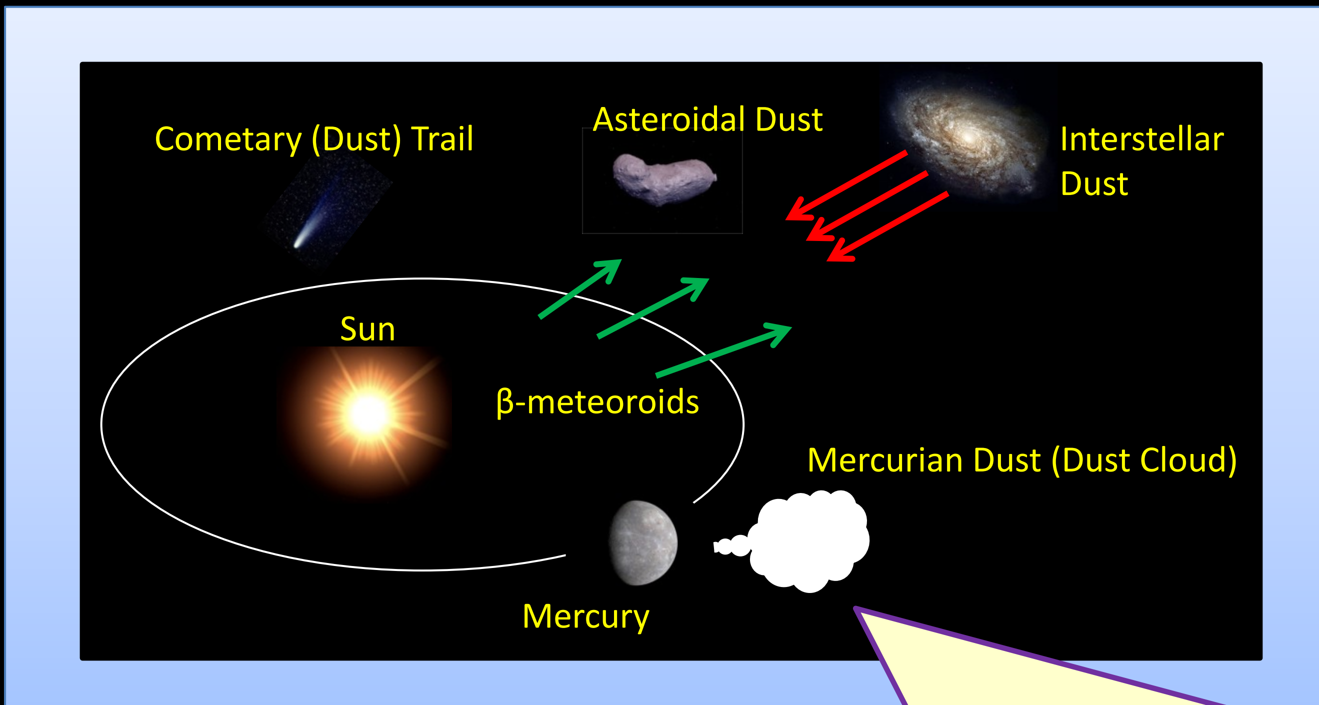
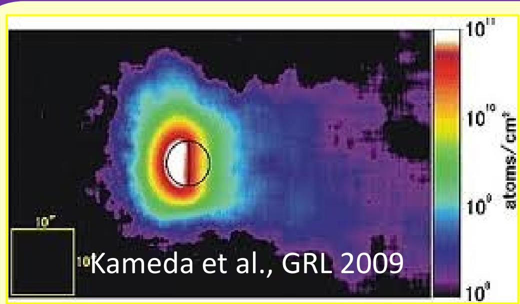
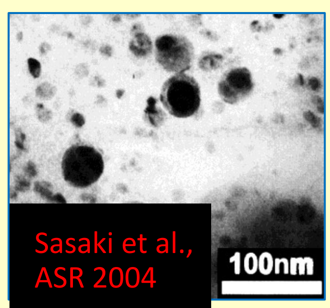
Dust environment around Mercury



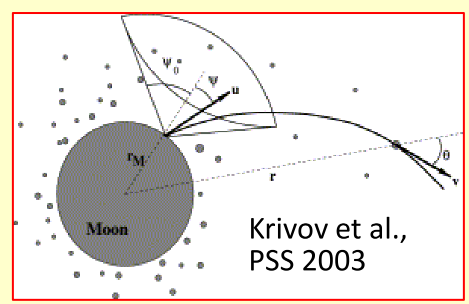
- The goal of the MDM is the observation of Mercury ambient dust particles and dust particles in the inner solar system.



Na atmosphere



Space Weathering



Dust Cloud

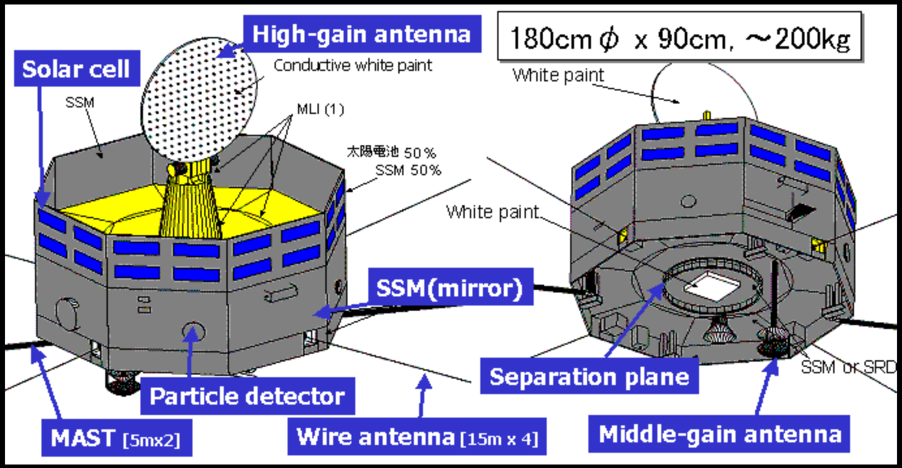
Science Significance of Dust Observation in Mercury's Orbit

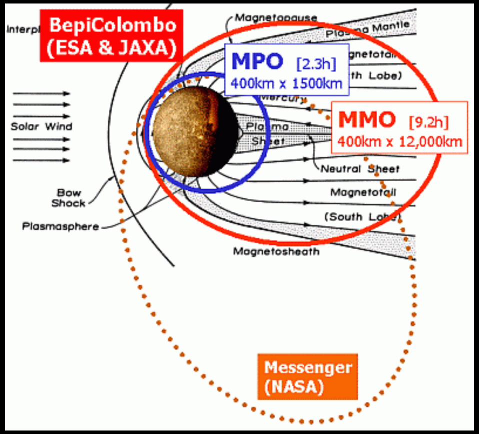
Dust sciences related to Mercury	
Dust to Mercury (V_{orbit} = 47.5 km/s V_{rel} > 6 km/s)	• Investigation of temporal and directional variations of dust influx throughout Mercurian orbit to identify the key meteoroid sources. • Assessment of meteoroid impact contribution to the formation of the tenuous Na atmosphere. • Constraint to the chronology of the Mercurian surface by space weathering. • Estimate external mass accretion rate to the Mercurian surface
Dust from Mercury ($V_{esc.}$= 4.25 km/s)	• Search for Mercurian dust ejection (e.g., temporal dust cloud) by meteoroid impacts, similar to the Jovian satellites. • Possible interaction with the magnetic field, similar to the Jovian satellite dust stream.
Dust within the Inner Solar System	Confirm the flux and size distribution as a function of the heliocentric distance (0.31-0.47 AU) . In-situ measurement to constrain zodiacal dust cloud distribution model.
Dust sciences of the inner solar system	
Cometary Dust	Possible encounters with the cometary dust trails and highly eccentric trajectories.
β Meteoroids	Direct flux measurement in the vicinity of Mercury (0.31-0.47 AU) help to understand mechanism and location.
Interstellar Dust	Possible detection of large interstellar dust (>=1 micron) coming into close to the sun.

Mercury Dust Monitor:overview

Parameter	Value/description
Sensor	Piezo-electric ceramics
Material	Lead zirconate titanate (PZT)
Dimension	4 cm x 4 cm x 2 mm, (x 4)
Area	64 cm^2 (total)
Resonance freq.	~ 1.1 MHz
Operational temp.	−160 to 200 degC (for sensor)
Sensor frame	125 x125 x7 mm^3, CFRP
Field of view	Azimuth 360 deg
	Elevation +/- 90 deg
Angular resolution	<180 deg
Sensitivity	>~ 1 pg km/s
Location	On the side panel of MMO
Mass	MDM-S (sensor) 220 g
	MDM-E (electronics) 381 g
Power consumption	3.0 W at the maximum

Bepi Colombo MMO





- The spacecraft will be launched in 2015. After arriving at Mercury in 2022, it will observe Mercury for 1 year and more.
- Bepi-Colombo MMO is a spin-stabilized spacecraft. The MDM will be installed on the side panel.
- The MMO will be in an elliptic orbit around Mercury with the perihermion of 600 km and the aphermion of 11624 km. The orbital inclination is 90°, oribital period is 9.3h. The Mercury-centric dependence of dust flux will be investigated.

Dust sensor in Mercury mission

Constrains

Due to the severe thermal environment in Mercury orbit , limited resource, and far remote operation, the MDM sensor is required to be:

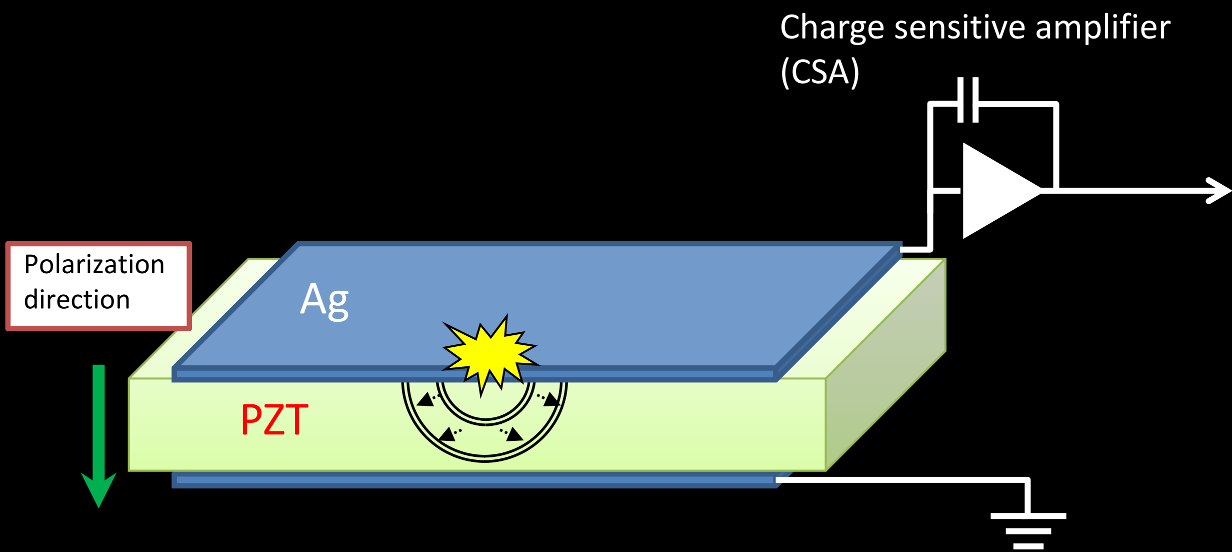
- fully functioned in high temperature in Mercury orbit.
- Intense sunlight condition
- Radiation damage from long-term exposure and solar flare

Adoption of PZT sensor

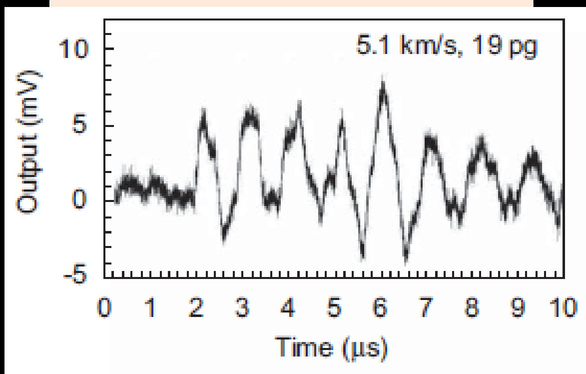
The solution is "PZT sensor" because of:

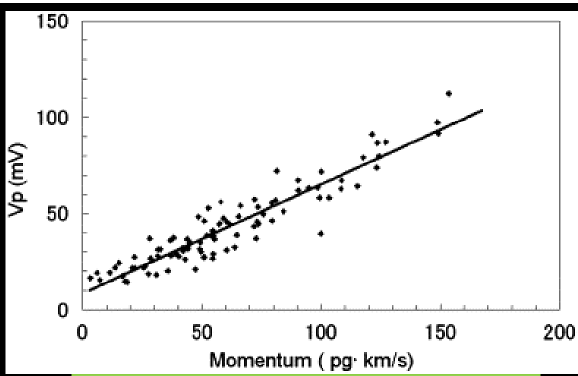
- Fully functioned at high temperature (~200℃)
- Long term stability
- Enough tolerance of radiation damage
- Compactness

Piezoelectric sensor



Hypervelocity dust impact signal read out by CSA

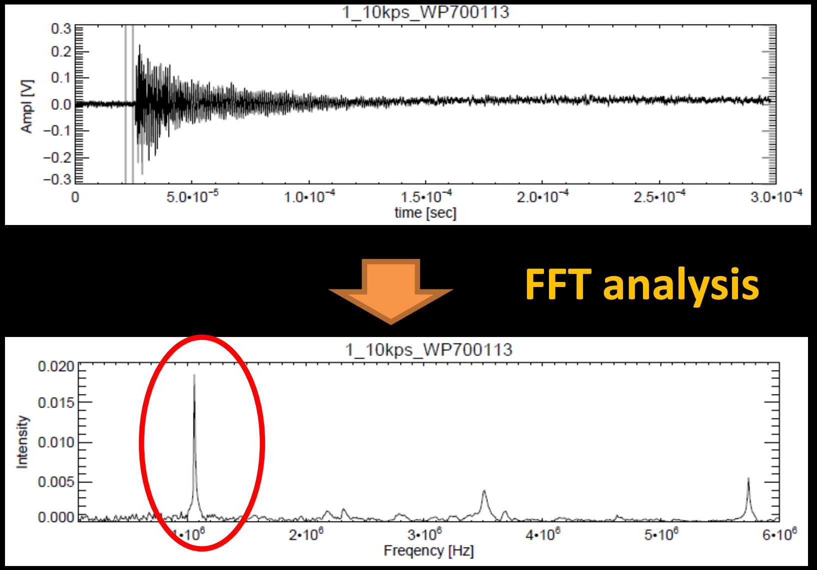


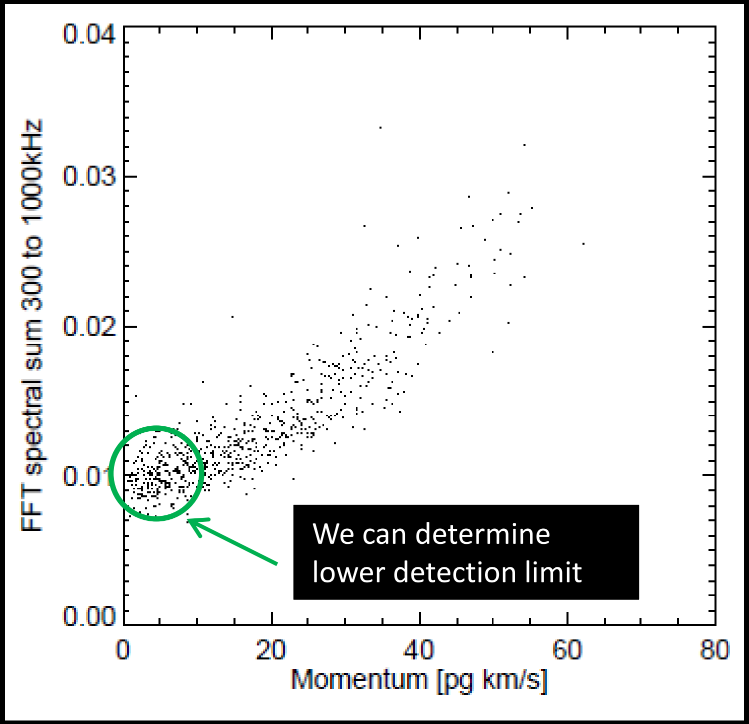


Momentum vs signal amplitude

- Thin silver layers put on the surface of PZT plate as electrodes for signal readout.
- Impulsive force by impact is applied to the surface, and stress is generated. The stress propagates as wave (about 4km/s in PZT) in and on PZT.
- The stress makes strain in PZT crystal, so that the electric filed is generated by piezoelectric effect. Charges are induced at the electrodes on the surfaces.

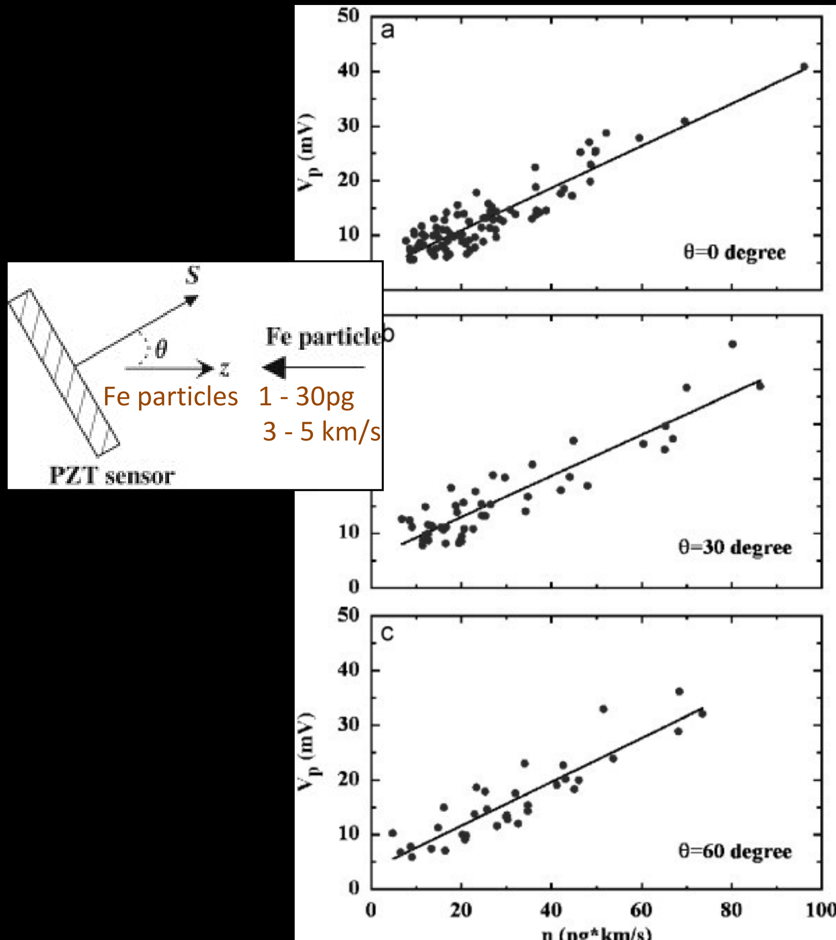
Signal analysis





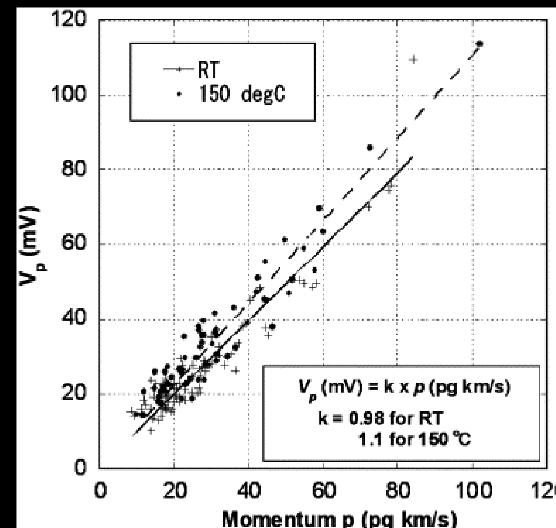
PZT sensor as dust monitor

Incident-angle dependence



Little dependence on incident angle was found in accelerator experiments.

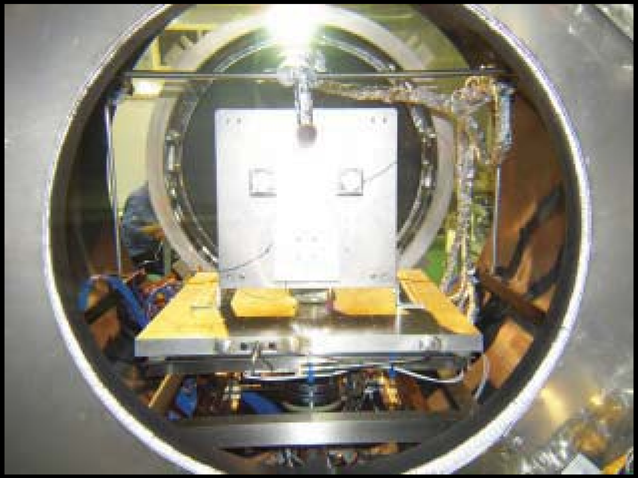
Temperature dependence

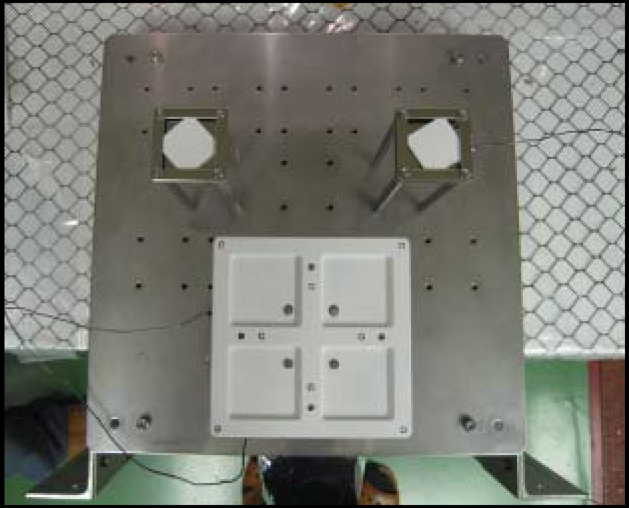


CSA suppresses temperature dependence of PZT output signal.

Nogami et al. PSS (2010)

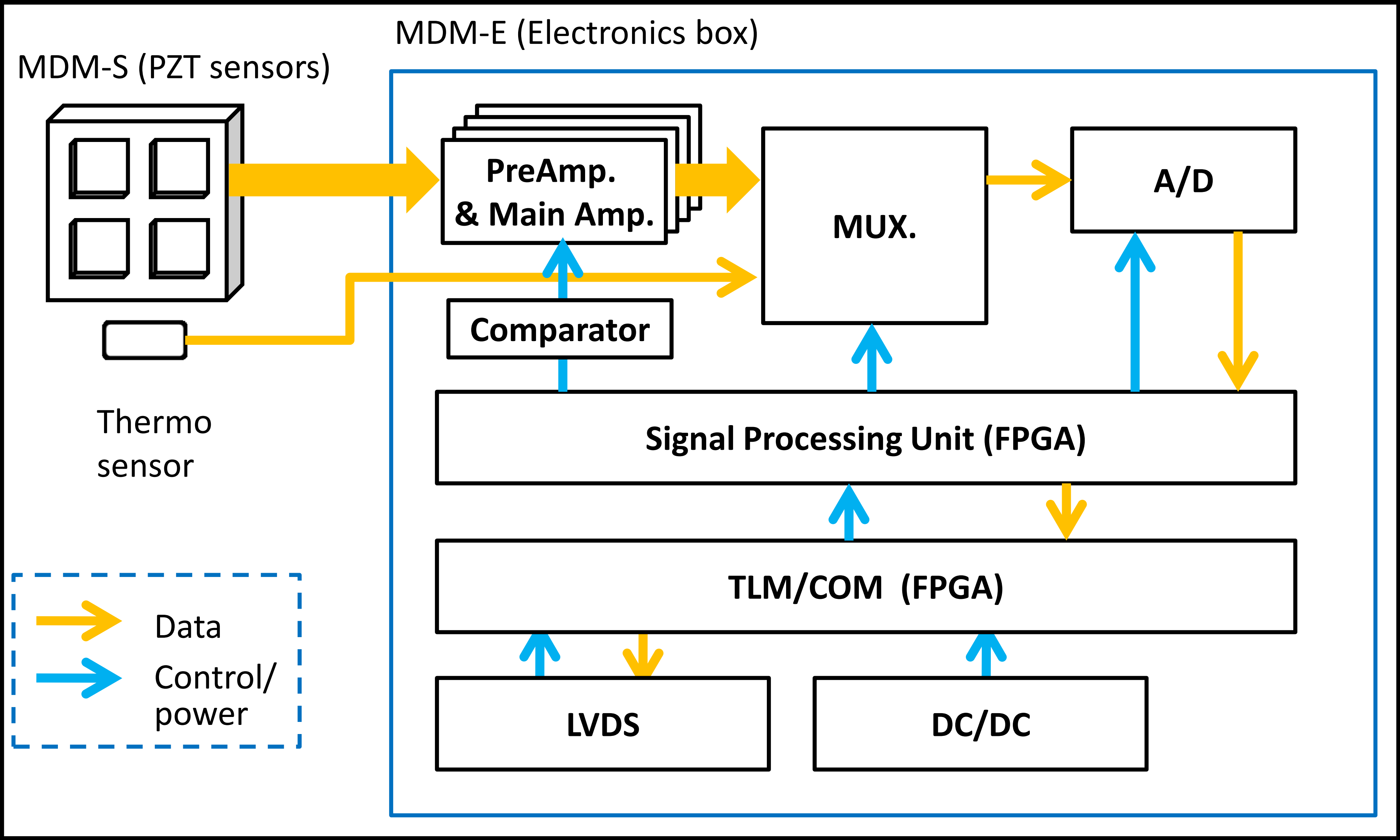
High temperature environment



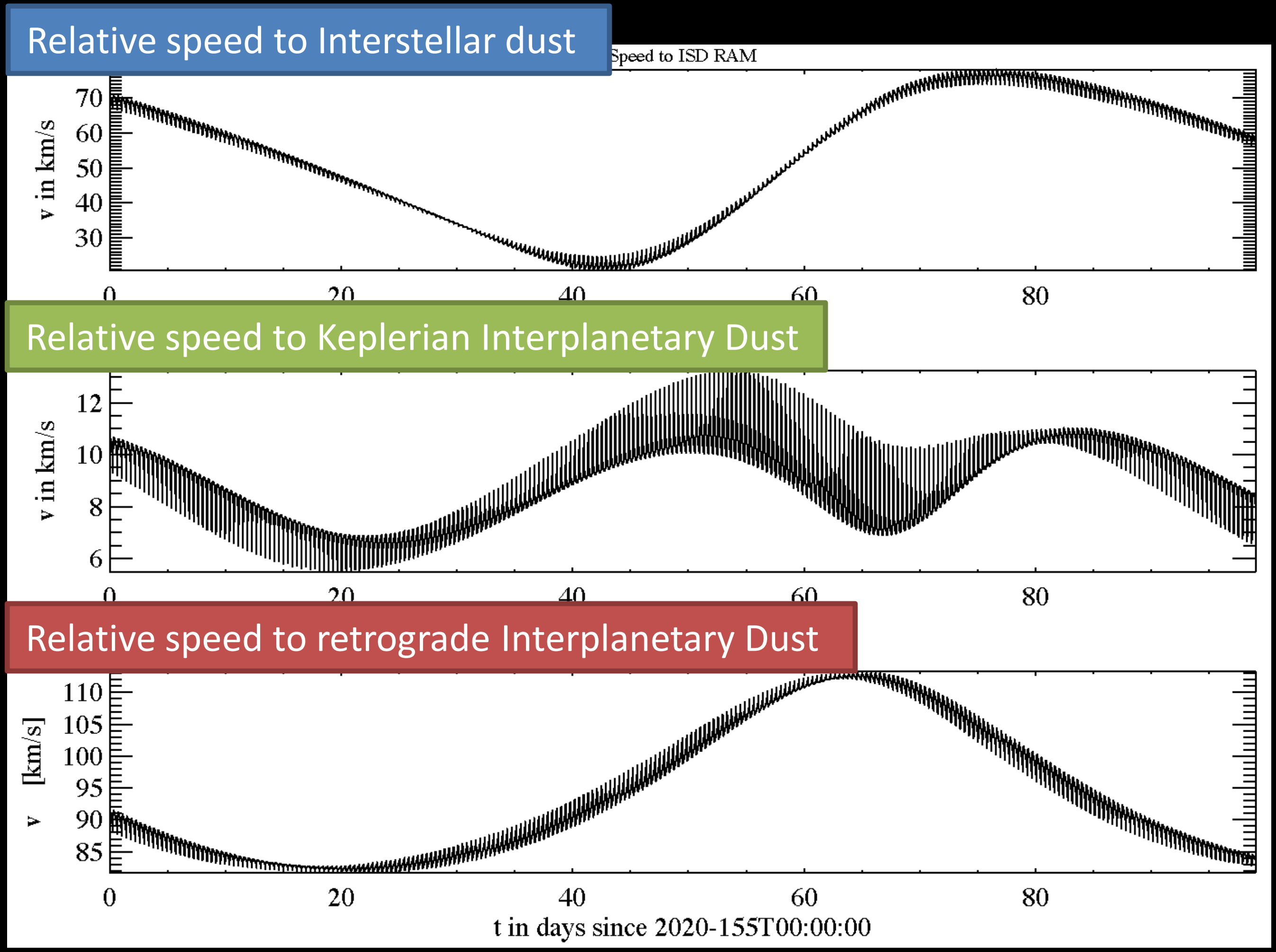


- To prevent the sunlight, the surface is finished with white paint(α=0.40, ε=0.86), otherwise the surface can become higher than Curie temperature of PZT (~300˚C).
- Owing to the white paint, the maximum temperature of the surface is 170˚C or less.

Functional Block Diagram of MDM

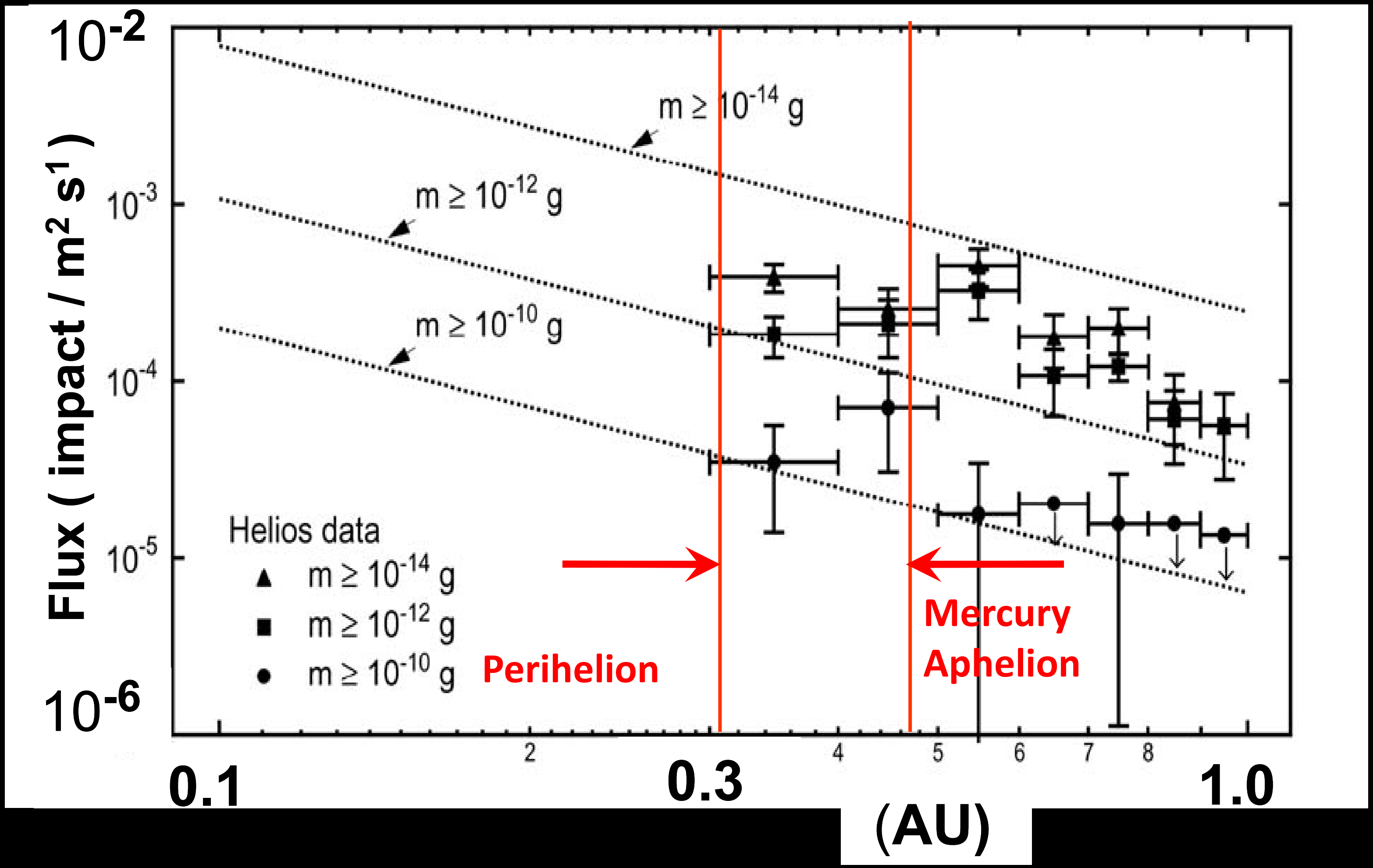


Impact speed to MDM sensor in Mercury orbit



Dust flux around Mercury's orbit

from Mann et al. 2003



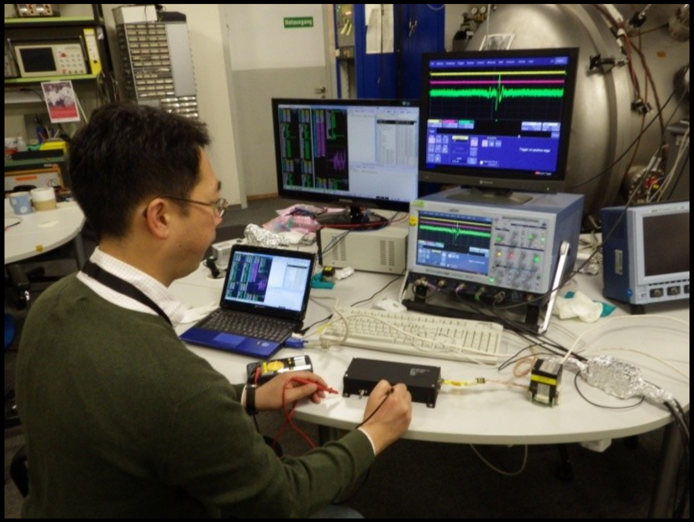
$10^{-3} m^{-2} s^{-1}$ corresponding to 0.5 hits/day by 64 cm^2 sensor

Expected data

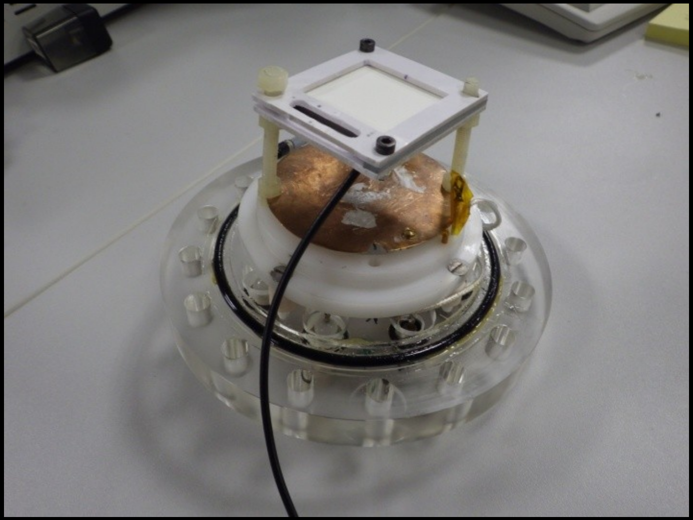
- The number of impacts on the monitor is expected to be 0.5 to 1 hits per day for interplanetary dust and about 10 hits per day for Mercurian dust.
- The time of an impact event will be recorded by using a clock counter data from the MMO system and the time precision is about 2 ms (1/512 s). The incoming direction of incident dust particles can be estimated from the clock counter value indicating the pointing direction of the MDM according to sun direction.
- 100 μs length data are recorded after impact by (10 ~ 40 MHz) 16bit ADC.
- 1 impact event has 8 kbyte, however, there will be much more noise events. So, for safety, data storage is prepared for 100 events / day.
- 8 kbyte x 100 = 0.8 Mbyte / day, status and HK data = 3 kbyte / day

Current status

Dust Acceleration Test Campaign in Heidelberg



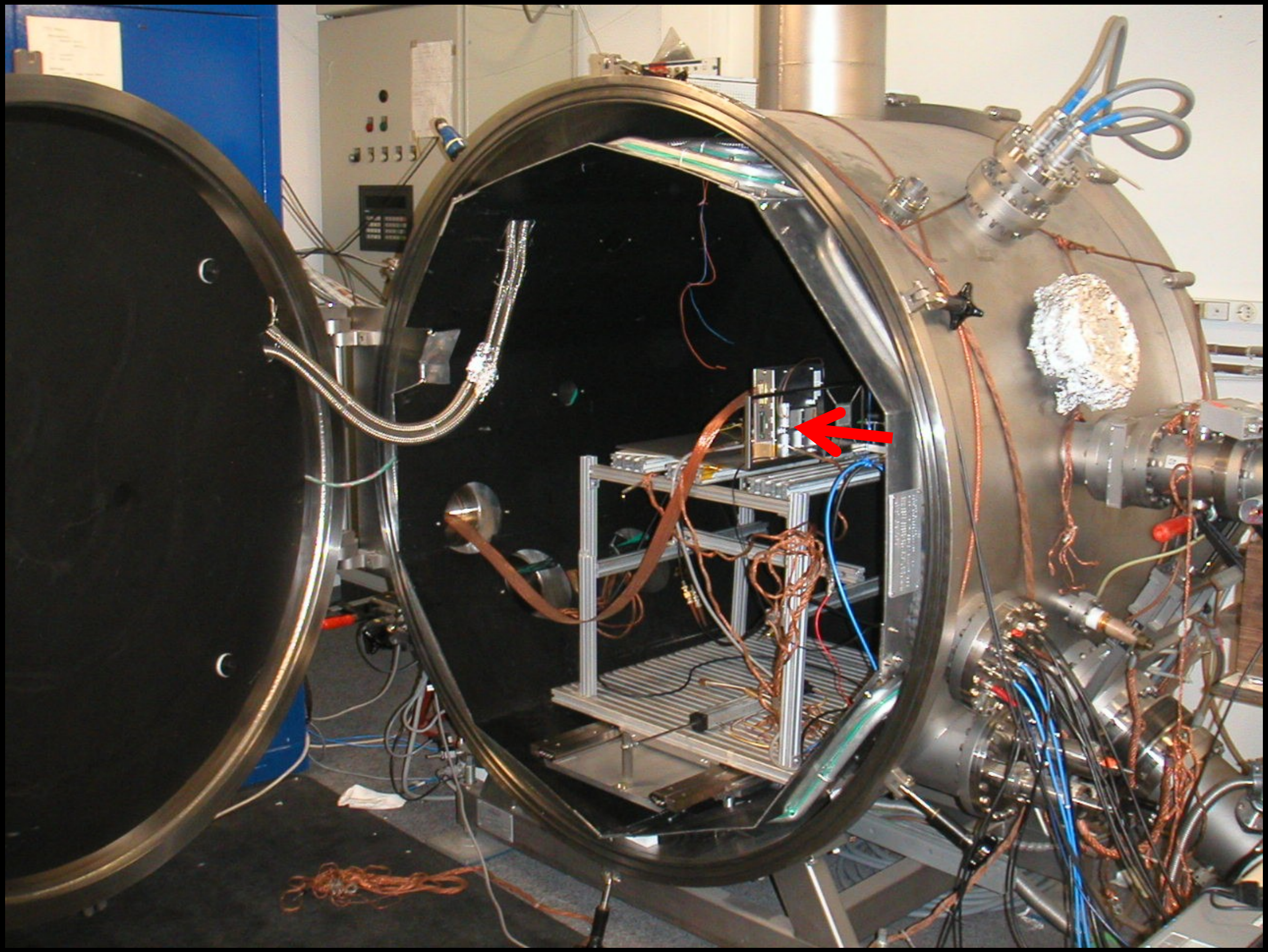
For qualification and evaluation of MDM functionality, we have implemented a dust acceleration test campaign using a high voltage Van de Graaff dust accelerator at the Max Planck Institute for Nuclear Physics in Heidelberg, in April 2012.



Left: We have 16 PZT sensors and applied “White Paint” to 8 sensors out of them. Ones with WP were impacted with accelerated dust for checkout.

Right: For evaluation of signal triggering and amplifying gain, a flight spare of MDM-E was used to read out signal from an attached sensor.

PZT sensor calibration experiment in Max-Plank Institute (Heidelberg)



Summary

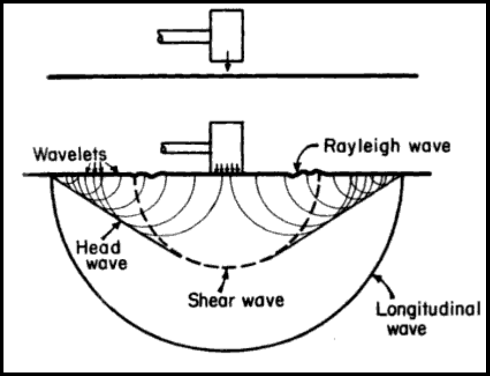
- BepiColombo MDM uses PZT sensor because of compactness, thermal resistance and radiation hardness.
- PZT sensor with the total aperture selected.
- MDM will measure dust environment around Mercury from 2020 for 1 year and more.
- The sensor has 64 cm^2 for the total aperture and expected impacts will be about 0.5 impact/day for IPD and about 5 to 10 impacts/day for Mercurian dust.
- Calibration experiments have been performed with the electrostatic accelerators and the light gas gun.

Thank you for paying attention

Energy balance

Longitudinal wave
-> Electric signal produced
by Piezoelectric effect

Wave	Energy distribution
Longitudinal	7%
Shear	26%
Surface	67%



Impact collision in various speed

Impact speed		Phenomenon	
Very slow	< 0.5m/s	Elastic	Kinetic energy is conserved.
Slow	0.5 m/s – 1km/s	Elastic, non-elastic	Energy is partly dissipated due to viscosity.
Fast	1km/s – 10 km/s	Non-elastic	Kinetic energy is not conserved due to destruction and/or evaporation.
Hypervelocity	> 10 km/s	Non-elastic	Projectile is fully evaporated and crater is created.

Momentum transfer is proportion to the momentum of the incident dust particle.